AD ______
TECH REPORT 68-2
SEPT 1968

TECHNICAL REPORT

MACROBEHAVIOR OF DEVELOPMENT COSTS AND ESTIMATES (STEC PLOTS)

HORACE SCHOW II

SYSTEMS AND COST ANALYSIS DIVISION
COMPTROLLER AND DIRECTOR OF PROGRAMS
U.S. ARMY MATERIEL COMMAND
WASHINGTON, D.C. 20315

28

TECHNICAL REPORT 68-2

MACROBEHAVIOR OF DEVELOPMENT COSTS AND ESTIMATES (STEC PLOTS)

HORACE SCHOW II*

September 1968

* The views of the author do not purport to reflect the position of the Department of the Army or the Department of Defense.

SYSTEMS AND COST ANALYSIS DIVISION
COMPTROLLER AND DIRECTOR OF PROGRAMS
US ARMY MATERIEL COMMAND
WASHINGTON, D. C. 20315

TABLE OF CONTENTS

ABSTRACT

This report provides the macrobehavior of development costs and estimates for these five systems: (1) PERSHING missile system; (2) SERGEANT missile system; (3) M561 (GAMA GOAT) truck; (4) SHERIDAN vehicle; and (5) Advanced Serial Fire Support System (AAFSS)(AH-56A). The STEC plot is developed to present the normalized development data. A new RDTE quantitative macrobehavior measure, the EFFICACY RATING, is developed to describe, not judge, the development phase of a weapon system.

I. INTRODUCTION

"When we face up to the problem of developing a substantial (operations research) theory we see that, as in all science, two complementary approaches are open to us, (i) to gather facts and (ii) to formulate hypotheses or concepts. The plain truth is that we have very few of either." These were the words of Dr. E. R. R. Holmberg (reference 1), Director of Operational Science and Research, The British War Office.

This "fact-gathering" report presents the case histories of estimates of development costs for several military systems. Peck and Scherer (reference 2) did the initial work of this type in their comprehensive analysis of the development costs of twelve aircraft and missile systems. They computed that the average development cost factor for the twelve Air Force systems was 3.2 where the development cost factor was defined as the actual development cost divided by the original development cost estimate. It is the purpose of this report to present historic estimates of development costs and the final approved development programs for these systems:

1. M561 (GAMA GOAT) truck
2. Advanced Aerial Fire Support System (AAFSS)
3. PERSHING missile
4. SERGEANT missile
5. SHERIDAN vehicle

The term "development costs" means the costs included in the Research-Development-Test-Evaluation (RDTE) phase of the overall program. The format for the data display is a normalized graph with a dimensionless time ratio on the abscissa and a dimensionless cost ratio (the inverse of the Peck-Scherer development factor) on the ordinate. This particular format is called a STEC PLOT since it arose from a "Study of Trends and Escalation of Costs" by the author at the Headquarters, US Army Materiel Command. It was far easier to get data for the final approved RDTE program than it was for estimates of future development costs where, for example, in one case the estimates were made 14 years ago. The various source documents were not self-consistent in all cases and various adjustments and corrections had to be made. No doubt every researcher in old cost estimates has found this to be the case. The source documents are quoted.

System managers should be aware of these trends and historical data. It is emphasized that these data and resultant plots are descriptive and not normative. No attempt is made here to say that these trends are desirable or, on the other hand, particularly undesirable. However, the very fact that these trends have occurred with some degree of regularity in the past suggests that future systems may also exhibit the characteristic rise of the (e/C) curve (see section II) to about the same degree.

These data indicate the magnitude of the past understatement of development costs. Section VII gives the general reasons for the understating process.

This is not an analysis or critique of a particular system. These happened to be readily available data.

II. M561 (GAMA GOAT) Truck

The M561 1.25 ton truck is a diesel engine powered, lightweight, articulated vehicle with selective two or six wheel drive. It is intended that the M561, initially called the GAMA GOAT truck, will perform a combat support role during cross-country operations. Reference 3 is the cost-effectiveness study for this vehicle.

Figure 1 is the development STEC plot.

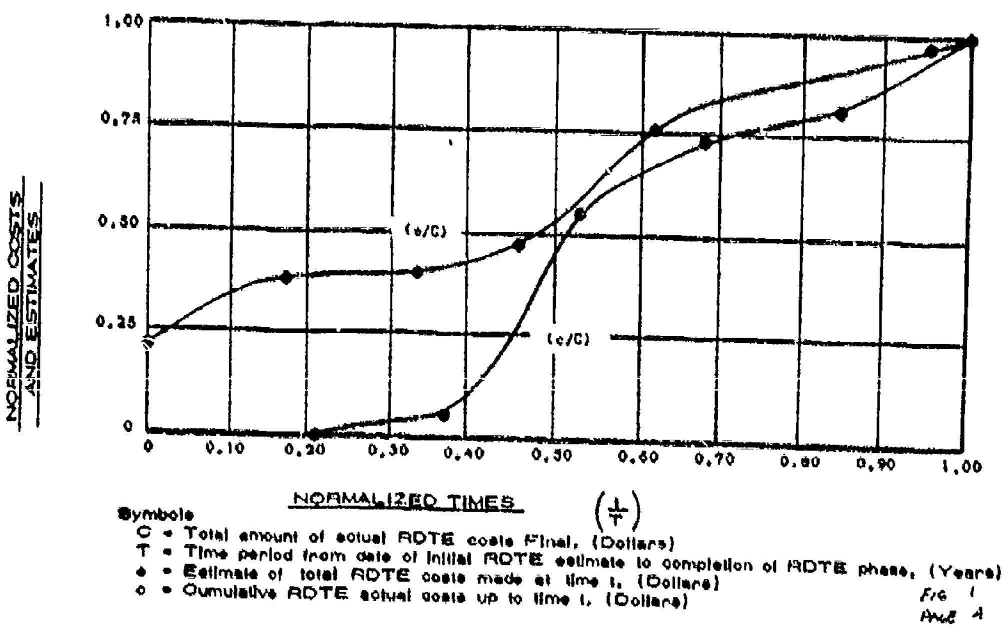


Figure 1. STEC PLOT: M561 (GAMA GOAT) TRUCK

The constant C is the total development cost.

The constant T is the development time as measured either from the earliest available estimate or the start of the actual development program to the completion of the RDTE phase.

The values of C and T are classified CONFIDENTIAL and will not be given in this unclassified report.

The letter e represents the estimate of total RDTE costs made at time t, and the letter c represents the cumulative RDTE actual program costs up to time t.

The dots on the STEC plot are plotted points representing an actual estimate or cumulative program at a particular time. In the sections which follow the dots are omitted at higher values of time when both curves approach unity.

The ratio (e/C) is a measure of the accuracy or the uncertainty of the estimate e made at time t. Its inverse at time t = 0, i.e., (C/e), is the Peck-Scherer development cost factor, which in this case would be 4.76. The (e/C) value at time t = 0, 1 March 1960, was 0.21 which means that the initial estimate was 21 percent of the final RDTE cost. The ratio (c/C) shows how the approved program varied as a function of time.

The data sources were:

1. The US Army Ordnance Corps RDTE Command Schedules of 1960, 1961, and 1962.

2. US Army Materiel Command RDTE Command Schedules of 1963 and 1965.

3. Project Manager's Master Plans.

4. M561 Technical Development Plan.

III. Advanced Aerial Fire Support System (AAFSS)

The Advanced Aerial Fire Support System (AAFSS), designated the AH-56A Cheyenne, is a rotary wing vehicle developed specifically as an integrated weapons system. The system is a two-place compound vehicle and all avionic, fire control, and weapons equipment. Reference 4 is the cost-effectiveness study.

Figure 2 gives the partial development STEC plot. Since this project will not complete its RDTE phase until FY-1971, these data are therefore an interim, rather than a final presentation.

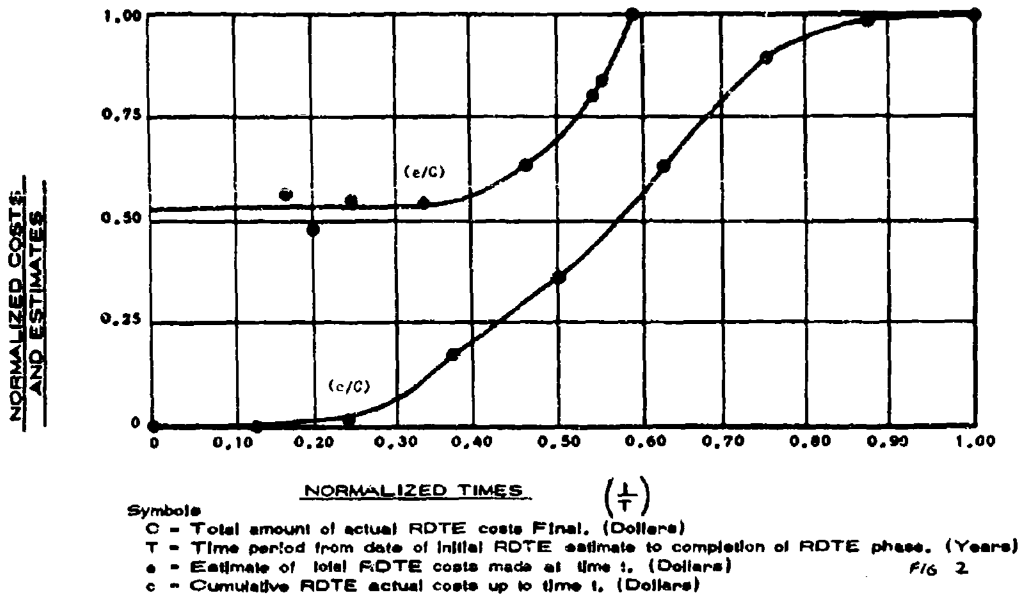


Figure 2. STEC PLOT: AH-56A SYSTEM

The data sources were:

1. US Army Materiel Command RDTE Command Schedules of 1963, 1965, 1966 and 1967.

2. Project Manager's "AAFSS Cost Estimate" of 1964.

3. Project Manager's Master Plans.

IV. PERSHING I Weapons System

The PERSHING I Weapon System provides nuclear fire power for general support of the field army and army group. PERSHING I is a mobile, surface-to-surface, ballistic missile system capable of fulfilling an extended range nuclear fire mission. The missile (XMGM-31A) is a multiple-stage, solid propellant, inertially guided missile.

Figure 3 gives the development STEC plot for the PERSHING I and does not include PERSHING IA.

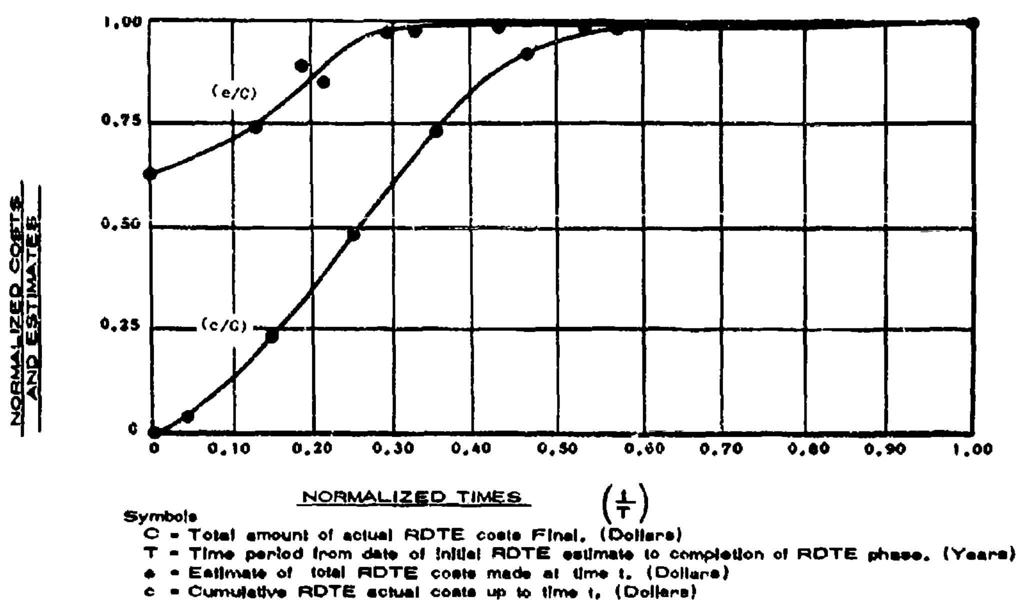


Figure 3. STEC PLOT: PERSHING SYSTEM (WITHOUT Ia)

The data sources were:

1. Pershing Missile System Plans of 1958, 1959, and 1960.

2. Project Manager's Master Plans.

3. US Army Materiel Command RDTE Command Schedules of 1963, 1965, 1966, and 1967.

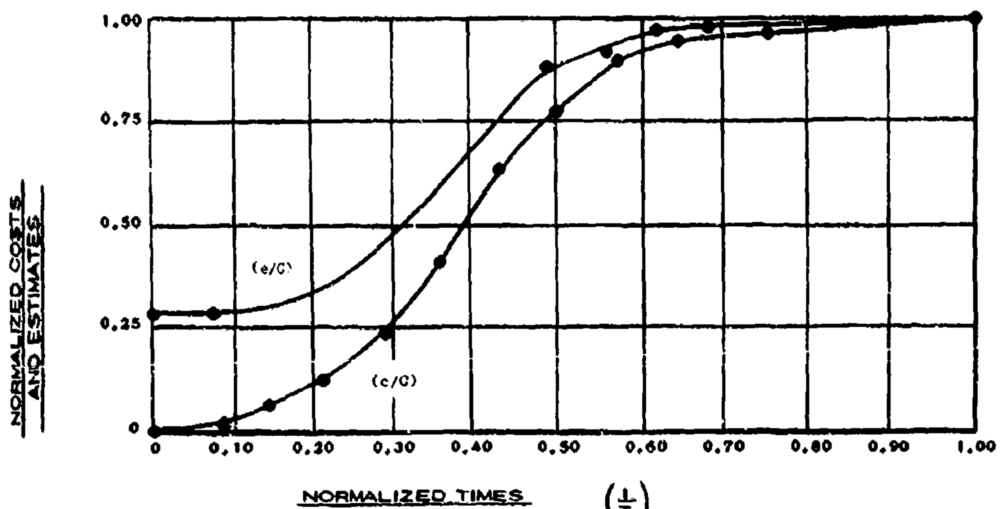
4. Pershing RDTE Program Status, 5 March 1968.

5. US Army Ordnance Corps Command Schedules of 1960, 1961, and 1962.

V. SERGEANT (Phase I) Weapons System

The SERGEANT Weapons System provides nuclear fire power for general support of corps and field armies. Its solid-fuel missile (XMGM-29 A) has a seventy-five nautical mile range. The development costs plotted are for Phase I and specifically do not include the Phase II improvements in the system.

Figure 4 gives the development STEC plot.



Symbols
C = Total amount of actual RDTE costs Final. (Dollars)
T = Time period from date of initial RDTE estimate to completion of RDTE phase. (Years)
e = Estimate of total RDTE costs made at time t. (Dollars)
c = Cumulative RDTE actual costs up to time t. (Dollars)

Figure 4. STEC PLOT: SERGEANT SYSTEM (WITHOUT PHASE II)

The data sources were:

1. Guided Missile Programs Data for Symington Committee, 19 April 1956.

2. SERGEANT Weapon System RDTE Funding Summary, provided by Project Manager's office on 15 February 1968.

3. "THE SERGEANT Program", Report Number 20-137, Jet Propulsion Laboratory, Pasadena, California, 1 October 1960.

4. US Army Materiel Command RDTE Command Schedules of 1963, 1965, 1966, and 1967.

5. US Army Ordnance Corps Command Schedules of 1960, 1961, and 1962.

VI. SHERIDAN System

The General Sheridan is a full-tracked amphibious armored reconnaissance/airborne assault vehicle armed with a 152-mm gun-launcher cannon that can fire either a guided missile or conventional ammunition.

Figure 5 gives the development STEC plot.

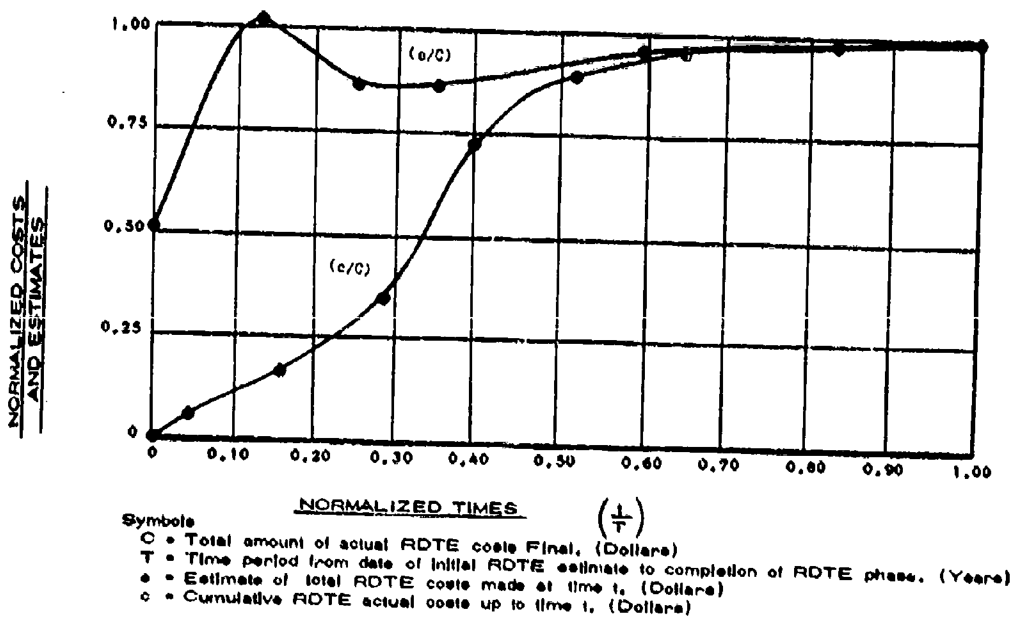


Figure 5. STEC PLOT: SHERIDAN SYSTEM

The data sources were:

1. Project Manager's Master Plans

2. US Army Materiel Command RDTE Command Schedules of 1963, 1965, 1966, and 1967.

3. US Army Ordnance Corps Command Schedules of 1960, 1961, and 1962.

VII. EFFICACY RATING

Since this is a fact-gathering report and not an analysis, specific comments on the latter will not be given. However, it can be said in general that the causes for the increasing trend in development costs are (1) inflationary trend of the economy; (2) changes in the configuration of the system being developed, usually toward a more complex system; (3) development program stretchout; (4) the transitional process which the purely engineering-based cost estimates undergo when converted into budget estimates; and (5) errors in the cost-estimating relationships with the bias for development estimates on the low side.

Figure 6 gives the range of the (e/C) curve for four systems, that is, Gamma Goat, Sergeant, Pershing, and Sheridan systems. The (e/C) MEAN curve is the arithmetic mean of the (e/C) curves of the four systems. The (e/C) HIGH curve is a composite of the highest (e/C) value of the four systems for a particular value of (t/T). The (e/C) LOW curve is a composite of the lowest (e/C) values. The value of the reciprocal of (e/C) MEAN at time = 0 is 2.4 which is to be compared with the Peck-Scherer value of 3.2. This lower value was expected since the four Army systems are less complex than the twelve Air Force systems selected by Peck and Scherer.

A new measure of the development process, the EFFICACY RATING, is given where the EFFICACY RATING (E) is a quantitative measure

(ranging from 0 to 1.0) to describe, not judge, the development phase of a weapons system. Previously defined RDTE measures include: (a) total RDTE cost C in dollars; (b) total RDTE duration T in years; and (c) the development cost factor (d.c.f.) of Peck and Scherer (reference 2). The STEC plots display these measures in normalized format where the value of the (e/C) curve at (t/T) = 0 corresponds to the development cost factor.

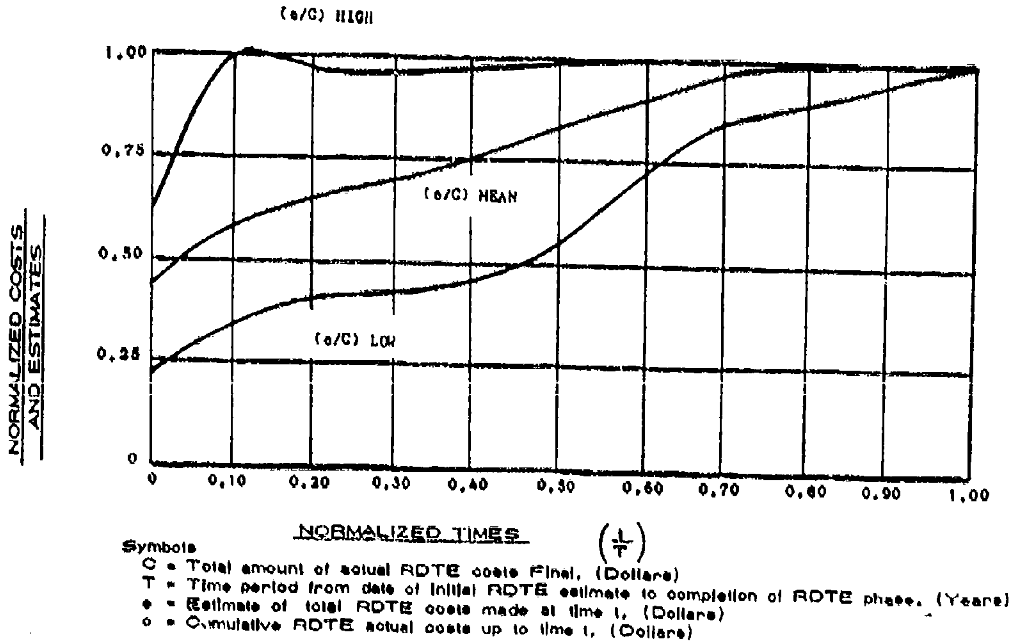


Figure 6. STEC PLOT: RANGE OF (e/C) CURVES FOR FOUR SYSTEMS (GAMA GOAT, SERGEANT, PERSHING, AND SHERIDAN)

These three macrobehavior measures while useful are not complete. See Figure 7. The curve A-B, labeled g(t) is the (c/C) curve; the g(t) notation is used to indicate that the curve is a function of time. Curves $f_1(t)$ and $f_2(t)$ are the (e/C) curves made respectively by Manager Number One (M1) and Manager Number Two (M2). The C, T, and d. c. f. values are equal. But the utilities of the estimates made by the two managers are not the same. Assuming that both managers have access to the same data, ceteris paribus, M2 by inspection of the STEC plot is the better manager in the sense that his estimates of the RDTE phase of this project are more meaningful. M1 is more passive and changes his estimates only as the actual costs change.

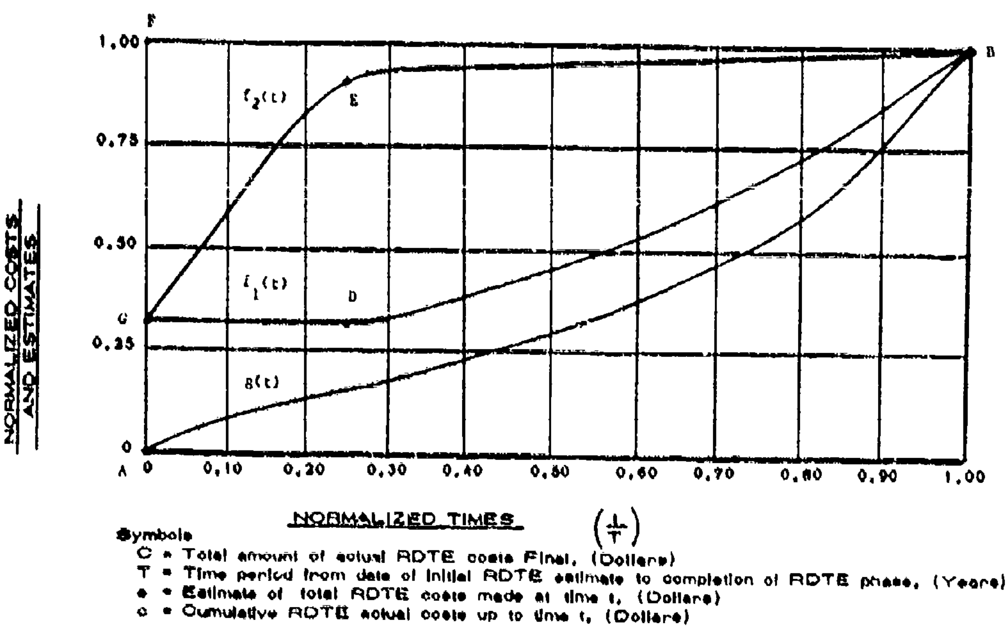
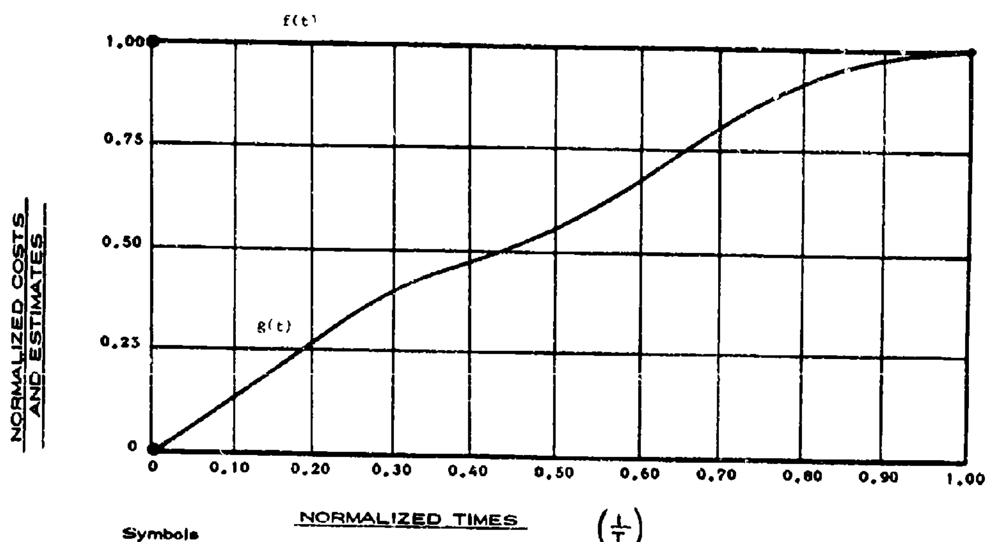


Figure 7. STEC PLOT WITH ESTIMATING BY TWO MANAGERS

M2, at (t/T) = 0.25, gives an estimate that is 0.90 C. M1 at the same time gives an estimate that is 0.30 C. M2 has realized that his first estimate was low and within a reasonably short time has produced a good one. M1 reacts slowly and changes his estimates only as g(t) increases.

The perfect manager (Figure 8) always estimates f(t) equal to C.



Symbols
C = Total amount of actual RDTE costs Final. (Dollars)
T = Time period from date of initial RDTE estimate to completion of RDTE phase. (Years)
e = Estimate of total RDTE costs made at time t. (Dollars)
c = Cumulative RDTE actual costs up to time t. (Dollars)

Figure 8. STEC PLOT OF THE "PERFECT" MANAGER

The perfectly imperfect manager (Figure 9) always estimates f(t) equal to g(t). Real world managers estimate somewhere between these extremes.

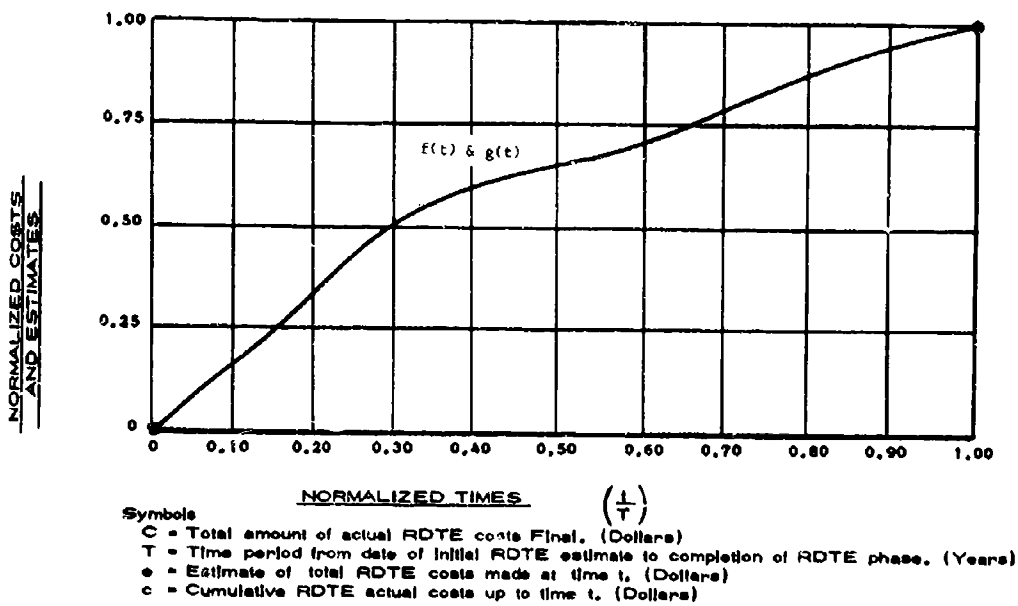


Figure 9. STEC PLOT OF THE "PERFECTLY IMPERFECT" MANAGER

The area for comparison is A-G-F-B of Figure 7. No attempt to judge the shape of the g(t) curve will be made. As the f(t) curve follows the F-B line the higher should be the rating. As the f(t)

curve follows the A-B line the lower should be the rating. The rating will be called the EFFICACY RATING and will be denoted by the capital letter E. This title avoids the confusion which could arise by calling the rating "efficiency" or "effectiveness".

Mathematically, the Efficacy Rating is defined as:

$$E = \frac{\int_0^1 \left[f(t) - g(t) \right] \, dt}{\int_0^1 \left[1 - g(t) \right] \, dt}$$

where $f(t)$ = (e/C) curve on a STEC plot.

and $g(t)$ = (c/C) curve on a STEC plot.

The perfect manager (Figure 8) has E equal to 1.0. The perfectly imperfect (Figure 9) manager has E equal to 0.

Note that E is a quantitative measure to describe the shapes of two curves. Figure 10 is a table showing possible combinations and reasons for the ratings. A low E value indicates something went wrong but a high E value does not necessarily insure that everything went right. The judgment of the decision maker is still required to interpret the E rating.

Description of Manager's Estimates	Description of Development Laboratory's Performance	Efficacy Rating (E)
Grossly overestimates RDTE cost either through ignorance or desire to play it safe.	Poor. Expends more funds than necessary. Possibly pads bill so as to exactly meet manager's cost estimate.	High: 0.9 or 1.0
Excellent cost estimate.	Excellent performance.	High: 0.9 or 1.0
Grossly underestimates RDTE costs either through ignorance or desire to "get his foot in the door."	Satisfactory performance.	Low: 0.1 or 0.2
Excellent cost estimate.	Poor performance. Expends more funds than necessary.	Low: 0.1 0.2
Low Cost Estimate.	Poor performance.	Low: 0.1 or 0.2

Figure 10. PERFORMANCE COMBINATIONS RESULTING IN HIGH OR LOW EFFICACY RATINGS

The EFFICACY RATINGS(E) for four systems are given below:

SYSTEM	E
PERSHING missile	0.74
GAMA GOAT truck	0.35
SERGEANT missile	0.38
SHERIDAN vehicle	0.79

VIII. REFERENCES

1. Dr. E. R. R. Holmberg. From the "Critical Appraisal Address, Britain" in the Report of the Eighth ABCA Discussions on Army Operational Research. Washington, D. C. 17-28 June 1963. Defense Documentation Center number AD 342283. CONFIDENTIAL. Prepared for the Office of the Chief of Research and Development, Department of the Army, by the Research Analysis Corporation of McLean, Virginia.

2. Peck, Merton J., and Scherer, Frederic M. The Weapons Acquisition Process: An Economic Analysis. Division of Research, Graduate School of Business Administration, Harvard University. Boston, 1962.

3. M561 Cost Effectiveness Study (U), revised September 1966. This report is CONFIDENTIAL and was prepared by the US Army Tank-Automotive Command in coordination with the Headquarters US Army Materiel Command and Ballistic Research Laboratory.

4. Advanced Aerial Fire Support System (AAFSS) (U), Phase II (Interim) Report, Supplement, Low-intensity Conflict, September 1967. This report is SECRET and was prepared under the direction of the US Army Combat Development Command (Institute of Special Studies).

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D	
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)	
1. ORIGINATING ACTIVITY (Corporate author) Headquarters, U. S. Army Materiel Command Washington, D. C. 20315	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP N/A
3. REPORT TITLE MACROBEHAVIOR OF DEVELOPMENT COST AND ESTIMATES (STEC PLOTS)	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)	
5. AUTHOR(S) (First name, middle initial, last name) Schow, Horace, II	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1968	29	4
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 68-2	
b. PROJECT NO.		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

This report provides the macrobehavior of development costs and estimates for these five systems: (1) PERSHING missile system; (2) SERGEANT missile system; (3) M561 (GAMA GOAT) truck; (4) SHERIDAN vehicle; and (5) Advanced Aerial Fire Support System (AAFSS)(AH-56A). The STEC plot is developed to present the normalized development data. A new RDTE quantitative macrobehavior measure, the EFFICACY RATING, is developed to describe, not judge, the development phase of a weapon system.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
research and development costs research and development estimates M561 (GAMA GOAT) truck SHERIDAN vehicle SERGEANT missile PERSHING missile CHEYENNE aircraft, AH-56A						